



Plant

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Plants are mainly multicellular, predominantly photosynthetic eukaryotes of the kingdom **Plantae**.

The term is today generally limited to the **green plants**, which form an unranked clade **Viridiplantae** (Latin for "green plants"). This includes the flowering plants, conifers and other gymnosperms, ferns, clubmosses, hornworts, liverworts, mosses and the green algae, and excludes the red and brown algae. Historically, plants formed one of two kingdoms covering all living things that weren't animals, and both algae and fungi were treated as plants; however all current definitions of "plant" exclude the fungi and some algae, as well as the prokaryotes (the archaea and bacteria).

Green plants have cell walls with cellulose and obtain most of their energy from sunlight via photosynthesis by primary chloroplasts, derived from endosymbiosis with cyanobacteria. Their chloroplasts contain chlorophylls a and b, which gives them their green color. Some plants are parasitic and have lost the ability to produce normal amounts of chlorophyll or to photosynthesize. Plants are characterized by sexual reproduction and alternation of generations, although asexual reproduction is also common.

There are about 300–315 thousand species of plants, of which the great majority, some 260–290 thousand, are seed plants (see the table below).^[5] Green plants provide most of the world's molecular oxygen^[6] and are the basis of most of Earth's ecologies, especially on land. Plants that produce grains, fruits and vegetables form humankind's basic foodstuffs, and have been domesticated for millennia. Plants play many roles in culture. They are used as ornaments and, until recently and in great variety, they have served as the source of most medicines and drugs. The scientific study of plants is known as botany, a branch of biology.

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Plants

Temporal range: Mesoproterozoic–present

Had'n **Archean** **Proterozoic** **Pha.**



Scientific classification

Domain: Eukaryota
(unranked): Archaeplastida
Kingdom: Plantae
sensu Copeland, 1956

Divisions

- †Nematophytes
- **Chlorophyta**
 - Palmophyllales
 - Prasinophyceae
 - Nephroselmidophyceae
 - Pseudoscourfieldiales
 - Pyramimonadophyceae
 - Mamiellophyceae
 - Scourfieldiales
 - Pedinophyceae
 - Chlorodendrophyceae
 - Trebouxiophyceae
 - Ulvophyceae
 - Chlorophyceae
- **Streptophyta** s.l.
 - Chlorokybophyta

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Definition

Plants are one of the two groups into which all living things were traditionally divided; the other is animals. The division goes back at least as far as Aristotle (384 BC – 322 BC), who distinguished between plants, which generally do not move, and animals, which often are mobile to catch their food. Much later, when Linnaeus (1707–1778) created the basis of the modern system of scientific classification, these two groups became the kingdoms Vegetabilia (later Metaphyta or Plantae) and Animalia (also called Metazoa). Since then, it has become clear that the plant kingdom as originally defined included several unrelated groups, and the fungi and several groups of algae were removed to new kingdoms. However, these organisms are still often considered plants, particularly in popular contexts.

Outside of formal scientific contexts, the term "plant" implies an association with certain traits, such as being multicellular, possessing cellulose, and having the ability to carry out photosynthesis.^{[7][8]}

Current definitions of Plantae

When the name Plantae or plant is applied to a specific group of organisms or taxon, it usually refers to one of four concepts. From least to most inclusive, these four groupings are:

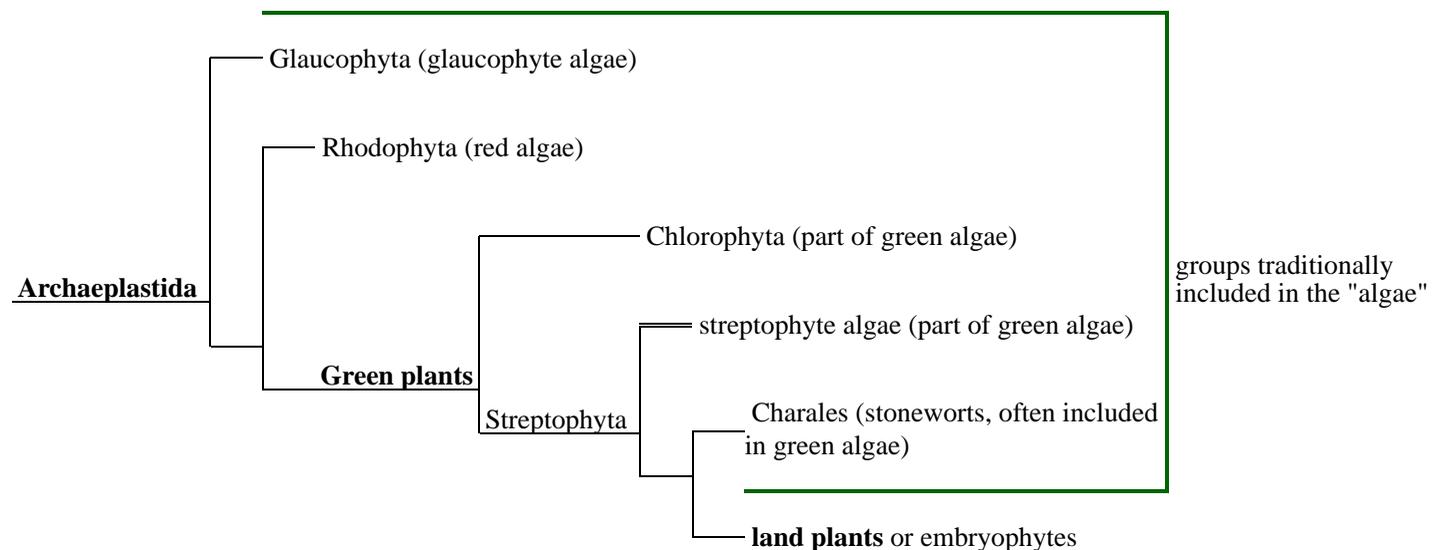
- Mesostigmatophyta
- Klebsormidiophyta
- Charophyta (stoneworts)
- Chaetosphaeriales
- Coleochaetophyta
- Zygnematophyta
- Embryophyta (land plants)

Synonyms

- Viridiplantae Cavalier-Smith 1981^[1]
- Chlorobionta Jeffrey 1982, emend. Bremer 1985, emend. Lewis and McCourt 2004^[2]
- Chlorobiota Kenrick and Crane 1997^[3]
- Chloroplastida Adl et al., 2005 ^[4]
- Phyta Barkley 1939 emed. Holt & Uidica 2007
- Cormophyta Endlicher, 1836
- Cormobionta Rothmaler, 1948
- Euplanta Barkley, 1949
- Telomobionta Takhtajan, 1964
- Embryobionta Cronquist et al., 1966
- Metaphyta Whittaker, 1969

Name(s)	Scope	Description
Land plants, also known as Embryophyta	<i>Plantae sensu strictissimo</i>	"Plants in the strictest sense". This group includes the liverworts, hornworts, mosses, and vascular plants, as well as fossil plants similar to these surviving groups (e.g., <i>Metaphyta</i> Whittaker, 1969, ^[9] <i>Plantae</i> Margulis, 1971 ^[10]).
Green plants , also known as Viridiplantae , Viridiphyta or Chlorobionta	<i>Plantae sensu stricto</i>	"Plants in a strict sense". This group includes the green algae, and land plants that emerged within them, including stoneworts. The names given to these groups vary considerably as of July 2011. Viridiplantae encompass a group of organisms that have cellulose in their cell walls, possess chlorophylls <i>a</i> and <i>b</i> and have plastids that are bound by only two membranes that are capable of storing starch. It is this clade that is mainly the subject of this article (e.g., <i>Plantae</i> Copeland, 1956 ^[11]).
Archaeplastida, also known as Plastida or Primoplantae	<i>Plantae sensu lato</i>	"Plants in a broad sense". This group comprises the green plants above plus Rhodophyta (red algae) and Glaucophyta (glaucophyte algae). This clade includes the organisms that eons ago acquired their chloroplasts directly by engulfing cyanobacteria (e.g., <i>Plantae</i> Cavalier-Smith, 1981 ^[12]).
Old definitions of plant (obsolete)	<i>Plantae sensu amplo</i>	"Plants in an ample sense". Old classifications, now obsolete, placed diverse algae, fungi or bacteria in <i>Plantae</i> (e.g., <i>Plantae</i> or <i>Vegetabilia</i> Linnaeus, ^[13] <i>Plantae</i> Haeckel 1866, ^[14] <i>Metaphyta</i> Haeckel, 1894, ^[15] <i>Plantae</i> Whittaker, 1969 ^[9]).

Another way of looking at the relationships between the different groups that have been called "plants" is through a cladogram, which shows their evolutionary relationships. The evolutionary history of plants is not yet completely settled, but one accepted relationship between the three groups described above is shown below.^{[16][17][18][19]} Those which have been called "plants" are in bold.



The way in which the groups of green algae are combined and named varies considerably between authors.

Algae

Algae comprise several different groups of organisms which produce energy through photosynthesis and for that reason have been included in the plant kingdom in the past. Most conspicuous among the algae are the seaweeds, multicellular algae that may roughly resemble land plants, but are classified among the brown, red and green algae. Each of these algal groups also includes various microscopic and single-celled organisms. There is good evidence that some of these algal groups arose independently from separate non-photosynthetic ancestors, with the result that many groups of algae are no longer classified within the plant kingdom as it is defined here.^{[20][21]}

The Viridiplantae, the green plants – green algae and land plants – form a clade, a group consisting of all the descendants of a

common ancestor. With a few exceptions among green algae, the green plants have the following features in common; cell walls containing cellulose, chloroplasts containing chlorophylls *a* and *b*, and food stores in the form of starch contained within plastids. They undergo closed mitosis without centrioles, and typically have mitochondria with flat cristae. The chloroplasts of green plants are surrounded by two membranes, suggesting they originated directly from endosymbiotic cyanobacteria.

Two additional groups, the Rhodophyta (red algae) and Glaucophyta (glaucophyte algae), also have chloroplasts which appear to be derived directly from endosymbiotic cyanobacteria, although they differ in the pigments which are used in photosynthesis and so are different in colour. All three groups together are generally believed to have a single common origin, and so are classified together in the taxon Archaeplastida, whose name implies that the chloroplasts or plastids of all the members of the taxon were derived from a single ancient endosymbiotic event. This is the broadest modern definition of the plants.

In contrast, most other algae (e.g. brown algae/diatoms, haptophytes, dinoflagellates, and euglenids) not only have different pigments but also have chloroplasts with three or four surrounding membranes. They are not close relatives of the Archaeplastida, presumably having acquired chloroplasts separately from ingested or symbiotic green and red algae. They are thus not included in even the broadest modern definition of the plant kingdom, although they were in the past.

The green plants or Viridiplantae were traditionally divided into the green algae (including the stoneworts) and the land plants. However, it is now known that the land plants evolved from within a group of green algae, so that the green algae by themselves are a paraphyletic group, i.e. a group that excludes some of the descendants of a common ancestor. Paraphyletic groups are generally avoided in modern classifications, so that in recent treatments the Viridiplantae have been divided into two clades, the Chlorophyta and the Streptophyta (or Charophyta).^{[22][23]}

The Chlorophyta (a name that has also been used for *all* green algae) are the sister group to the group from which the land plants evolved. There are about 4,300 species^[24] of mainly marine organisms, both unicellular and multicellular. The latter include the sea lettuce, *Ulva*.

The other group within the Viridiplantae are the mainly freshwater or terrestrial Streptophyta, which consists of the land plants together with the Charophyta, itself consisting of several groups of green algae such as the desmids and stoneworts. (The names have been used differently, e.g. Streptophyta to mean the group that excludes the land plants and Charophyta for the stoneworts alone or the stoneworts plus the land plants.) Streptophyte algae are either unicellular or form multicellular filaments, branched or unbranched.^[23] The genus *Spirogyra* is a filamentous streptophyte alga familiar to many, as it is often used in teaching and is one of the organisms responsible for the algal "scum" that pond-owners so dislike. The freshwater stoneworts strongly resemble land plants and are believed to be their closest relatives. Growing underwater, they consist of a central stalk with whorls of branchlets, giving them a superficial resemblance to horsetails, species of the genus *Equisetum*, which are true land plants.

Fungi

The classification of fungi has been controversial until quite recently in the history of biology. Linnaeus' original classification placed the fungi within the Plantae, since they were unquestionably not animals or minerals and these were the only other alternatives. With later developments in microbiology, in the 19th century Ernst Haeckel felt that another kingdom was required to classify newly discovered micro-organisms. The introduction of the new kingdom Protista in addition to Plantae and Animalia, led to uncertainty as to whether fungi truly were best placed in the Plantae or whether they ought to be reclassified as protists. Haeckel himself found it difficult to decide and it was not until 1969 that a solution was found whereby Robert Whittaker proposed the creation of the kingdom Fungi. Molecular evidence has since shown that the most recent common ancestor (concestor), of the Fungi was probably more similar to that of the Animalia than to that of Plantae or any other kingdom.^[25]

Whittaker's original reclassification was based on the fundamental difference in nutrition between the Fungi and the Plantae. Unlike plants, which generally gain carbon through photosynthesis, and so are called autotrophs, fungi generally obtain carbon by breaking down and absorbing surrounding materials, and so are called heterotrophic saprotrophs. In addition, the substructure



Green algae from Ernst Haeckel's *Kunstformen der Natur*, 1904.

of multicellular fungi is different from that of plants, taking the form of many chitinous microscopic strands called hyphae, which may be further subdivided into cells or may form a syncytium containing many eukaryotic nuclei. Fruiting bodies, of which mushrooms are the most familiar example, are the reproductive structures of fungi, and are unlike any structures produced by plants.

Diversity

The table below shows some species count estimates of different green plant (Viridiplantae) divisions. It suggests there are about 300,000 species of living Viridiplantae, of which 85–90% are flowering plants. (Note: as these are from different sources and different dates, they are not necessarily comparable, and like all species counts, are subject to a degree of uncertainty in some cases.)

Diversity of living green plant (Viridiplantae) divisions

Informal group	Division name	Common name	No. of living species	Approximate No. in informal group
Green algae	Chlorophyta	green algae (chlorophytes)	3,800–4,300 [26][27]	8,500 (6,600–10,300)
	Charophyta	green algae (e.g. desmids & stoneworts)	2,800–6,000 [28][29]	
Bryophytes	Marchantiophyta	liverworts	6,000–8,000 [30]	19,000 (18,100–20,200)
	Anthocerotophyta	hornworts	100–200 [31]	
	Bryophyta	mosses	12,000 [32]	
Pteridophytes	Lycopodiophyta	club mosses	1,200 [21]	12,000 (12,200)
	Pteridophyta	ferns, whisk ferns & horsetails	11,000 [21]	
Seed plants	Cycadophyta	cycads	160 [33]	260,000 (259,511)
	Ginkgophyta	ginkgo	1 [34]	
	Pinophyta	conifers	630 [21]	
	Gnetophyta	gnetophytes	70 [21]	
	Magnoliophyta	flowering plants	258,650 [35]	

The naming of plants is governed by the International Code of Nomenclature for algae, fungi, and plants and International Code of Nomenclature for Cultivated Plants (see cultivated plant taxonomy).

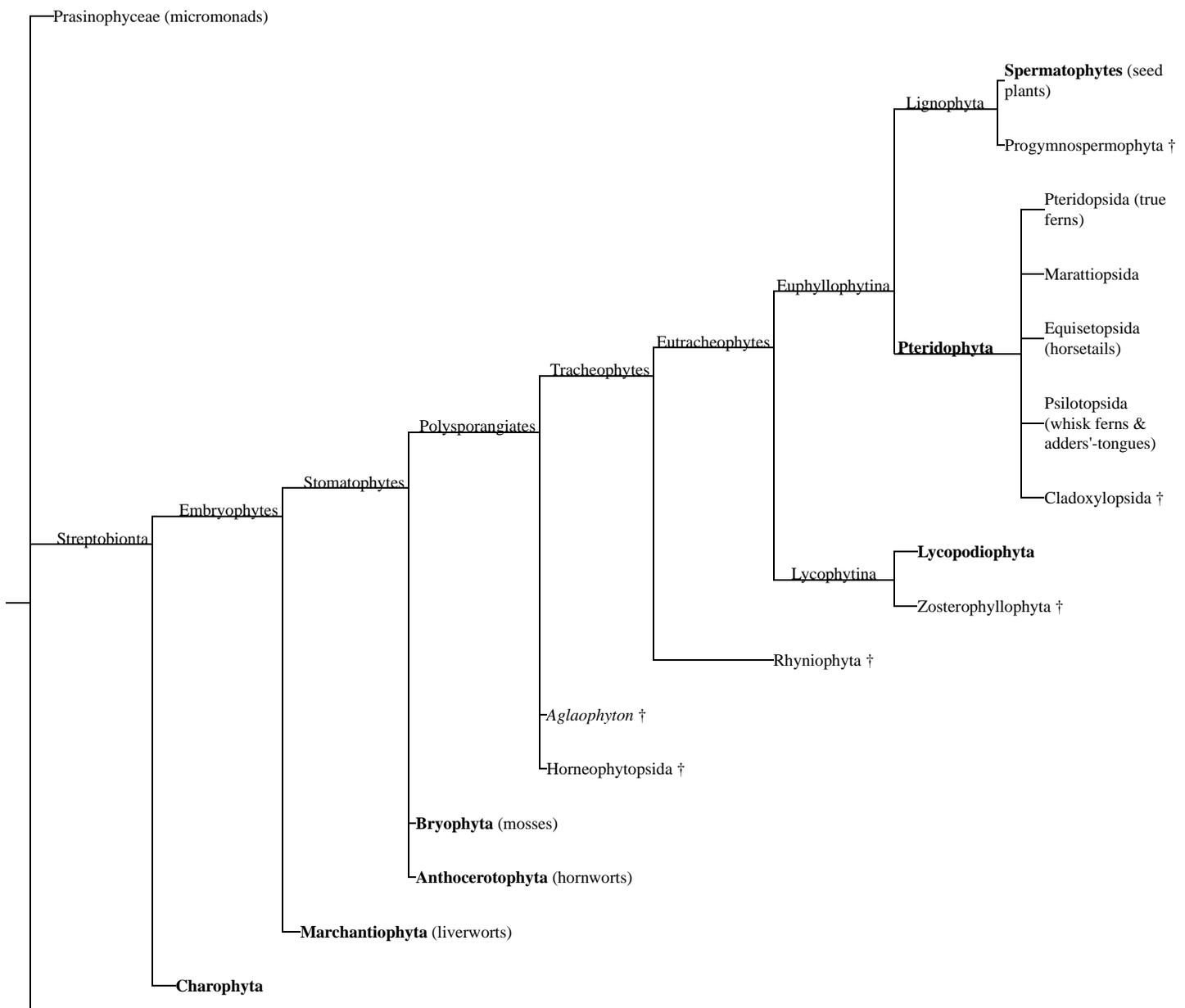
Evolution

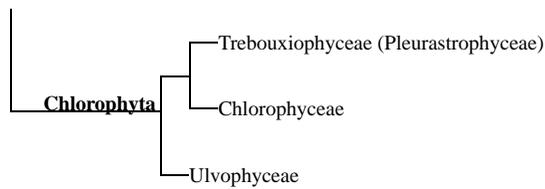
The evolution of plants has resulted in increasing levels of complexity, from the earliest algal mats, through bryophytes, lycopods, ferns to the complex gymnosperms and angiosperms of today. Plants in all of these groups continue to thrive, especially in the environments in which they evolved.

An algal scum formed on the land 1,200 million years ago, but it was not until the Ordovician Period, around 450 million years ago, that land plants appeared.^[36] However, new evidence from the study of carbon isotope ratios in Precambrian rocks has suggested that complex photosynthetic plants developed on the earth over 1000 m.y.a.^[37] For more than a century it has been assumed that the ancestors of land plants evolved in aquatic environments and then adapted to a life on land, an idea usually credited to botanist Frederick Orpen Bower in his 1908 book "The Origin of a Land Flora". A more recent alternative view, supported by genetic evidence, is that they evolved from single-celled algae that were already terrestrial.^[38] Primitive land plants began to diversify in the late Silurian Period, around 420 million years ago, and the fruits of their

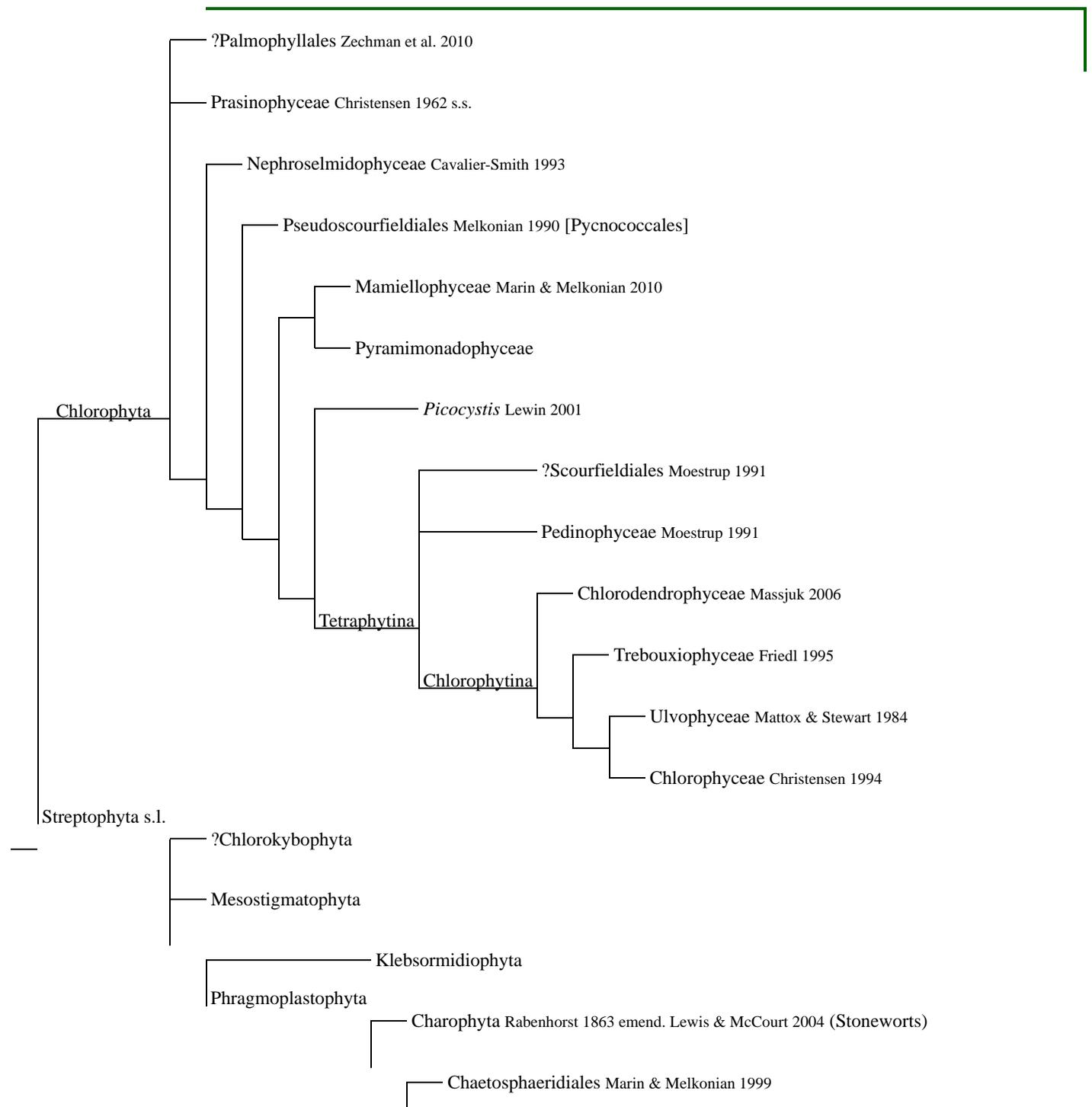
diversification are displayed in remarkable detail in an early Devonian fossil assemblage from the Rhynie chert. This chert preserved early plants in cellular detail, petrified in volcanic springs. By the middle of the Devonian Period most of the features recognised in plants today are present, including roots, leaves and secondary wood, and by late Devonian times seeds had evolved.^[39] Late Devonian plants had thereby reached a degree of sophistication that allowed them to form forests of tall trees. Evolutionary innovation continued after the Devonian period. Most plant groups were relatively unscathed by the Permian-Triassic extinction event, although the structures of communities changed. This may have set the scene for the evolution of flowering plants in the Triassic (~200 million years ago), which exploded in the Cretaceous and Tertiary. The latest major group of plants to evolve were the grasses, which became important in the mid Tertiary, from around 40 million years ago. The grasses, as well as many other groups, evolved new mechanisms of metabolism to survive the low CO₂ and warm, dry conditions of the tropics over the last 10 million years.

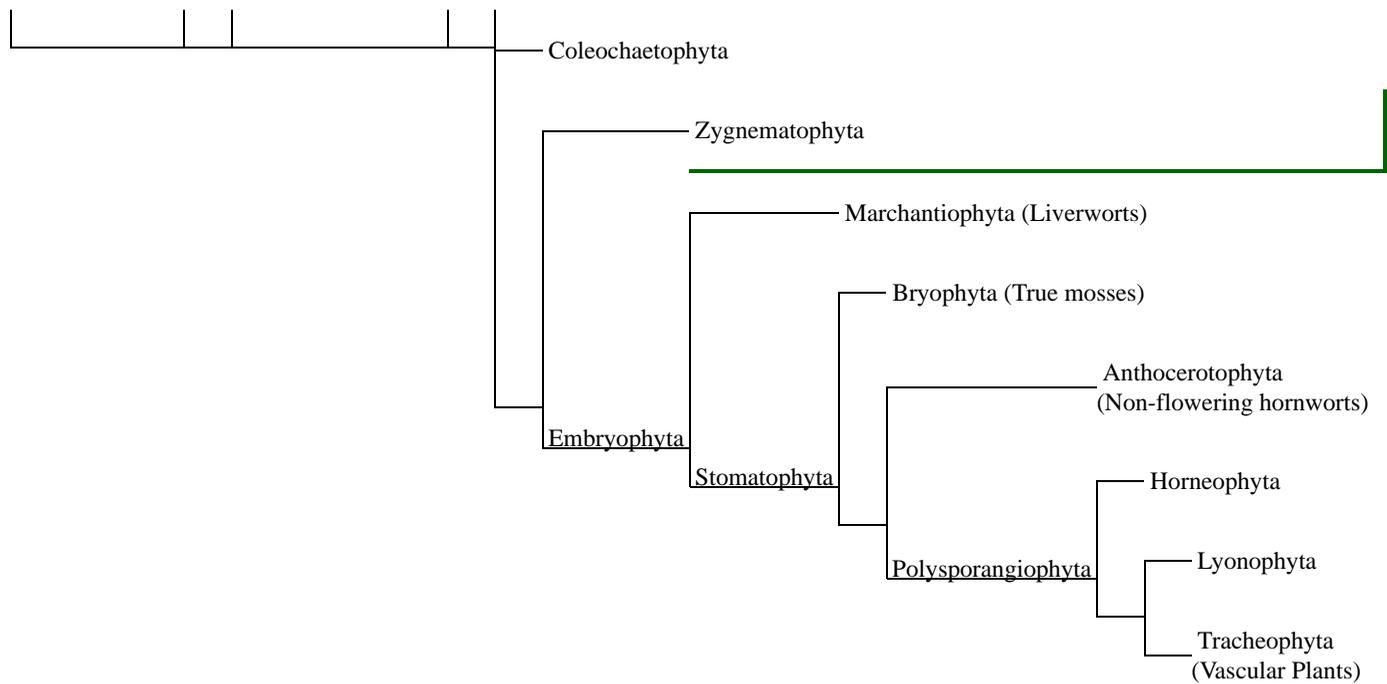
A 1997 proposed phylogenetic tree of Plantae, after Kenrick and Crane,^[40] is as follows, with modification to the Pteridophyta from Smith *et al.*^[41] The Prasinophyceae are a paraphyletic assemblage of early diverging green algal lineages, but are treated as a group outside the Chlorophyta.^[42] later authors have not followed this suggestion.





A newer proposed classification follows Leliaert et al. 2011^[43] and modified with Silar 2016^[44] for the green algae clades and Novíkov & Barabaš-Krasni 2015^[45] for the land plants clade. Notice that the Prasinophyceae are here placed inside the Chlorophyta.





Embryophytes

The plants that are likely most familiar to us are the multicellular land plants, called embryophytes. Embryophytes include the vascular plants, such as ferns, conifers and flowering plants. They also include the *bryophytes*, of which mosses and liverworts are the most common.

All of these plants have eukaryotic cells with cell walls composed of cellulose, and most obtain their energy through photosynthesis, using light, water and carbon dioxide to synthesize food. About three hundred plant species do not photosynthesize but are parasites on other species of photosynthetic plants. Embryophytes are distinguished from green algae, which represent a mode of photosynthetic life similar to the kind modern plants are believed to have evolved from, by having specialized reproductive organs protected by non-reproductive tissues.

Bryophytes first appeared during the early Paleozoic. They can only survive where moisture is available for significant periods, although some species are desiccation-tolerant. Most species of bryophytes remain small throughout their life-cycle. This involves an alternation between two generations: a haploid stage, called the gametophyte, and a diploid stage, called the sporophyte. In bryophytes, the sporophyte is always unbranched and remains nutritionally dependent on its parent gametophyte. The bryophytes have the ability to secrete a cuticle on their outer surface, a waxy layer that confers resistant to desiccation. In the mosses and hornworts a cuticle is usually only produced on the sporophyte. Stomata are absent from liverworts, but occur on the sporangia of mosses and hornworts, allowing gas exchange while controlling water loss.

Vascular plants first appeared during the Silurian period, and by the Devonian had diversified and spread into many different terrestrial environments. They developed a number of adaptations that allowed them to spread into increasingly more arid places, notably the vascular tissues xylem and phloem, that transport water and food throughout the organism. Root systems capable of obtaining soil water and nutrients also evolved during the Devonian. In modern vascular plants, the sporophyte is typically large, branched, nutritionally independent and long-lived, but there is increasing evidence that Paleozoic gametophytes were just as complex as the sporophytes. The gametophytes of all vascular plant groups evolved to become reduced in size and prominence in the life cycle.

The first seed plants, Pteridosperms (seed ferns), now extinct, appeared in the Devonian and diversified through the Carboniferous. In these the microgametophyte is reduced to pollen and the megagametophyte remains inside the



Dicksonia antarctica, a species of tree fern

megasporangium, attached to the parent plant. A megasporangium invested in protective layer called an integument is known as an ovule. After fertilisation by means of sperm deposited by pollen grains, an embryo develops inside the ovule. The integument becomes a seed coat, and the ovule develops into a seed. Seed plants can survive and reproduce in extremely arid conditions, because they are not dependent on free water for the movement of sperm, or the development of free living gametophytes.

Early seed plants are gymnosperms, as the ovules and subsequent seeds are not enclosed in a protective structure (carpels or fruit), but are found naked, typically on cone scales. Pollen typically lands directly on the ovule. Four surviving groups remain widespread now, particularly the conifers, which are dominant trees in several biomes.

Fossils

Plant fossils include roots, wood, leaves, seeds, fruit, pollen, spores, phytoliths, and amber (the fossilized resin produced by some plants). Fossil land plants are recorded in terrestrial, lacustrine, fluvial and nearshore marine sediments. Pollen, spores and algae (dinoflagellates and acritarchs) are used for dating sedimentary rock sequences. The remains of fossil plants are not as common as fossil animals, although plant fossils are locally abundant in many regions worldwide.

The earliest fossils clearly assignable to Kingdom Plantae are fossil green algae from the Cambrian. These fossils resemble calcified multicellular members of the Dasycladales. Earlier Precambrian fossils are known that resemble single-cell green algae, but definitive identity with that group of algae is uncertain.

The oldest known fossils of embryophytes date from the Ordovician, though such fossils are fragmentary. By the Silurian, fossils of whole plants are preserved, including the lycophyte *Baragwanathia longifolia*. From the Devonian, detailed fossils of rhyniophytes have been found. Early fossils of these ancient plants show the individual cells within the plant tissue. The Devonian period also saw the evolution of what many believe to be the first modern tree, *Archaeopteris*. This fern-like tree combined a woody trunk with the fronds of a fern, but produced no seeds.

The Coal measures are a major source of Paleozoic plant fossils, with many groups of plants in existence at this time. The spoil heaps of coal mines are the best places to collect; coal itself is the remains of fossilised plants, though structural detail of the plant fossils is rarely visible in coal. In the Fossil Grove at Victoria Park in Glasgow, Scotland, the stumps of *Lepidodendron* trees are found in their original growth positions.

The fossilized remains of conifer and angiosperm roots, stems and branches may be locally abundant in lake and inshore sedimentary rocks from the Mesozoic and Cenozoic eras. Sequoia and its allies, magnolia, oak, and palms are often found.

Petrified wood is common in some parts of the world, and is most frequently found in arid or desert areas where it is more readily exposed by erosion. Petrified wood is often heavily silicified (the organic material replaced by silicon dioxide), and the impregnated tissue is often preserved in fine detail. Such specimens may be cut and polished using lapidary equipment. Fossil forests of petrified wood have been found in all continents.

Fossils of seed ferns such as *Glossopteris* are widely distributed throughout several continents of the Southern Hemisphere, a fact that gave support to Alfred Wegener's early ideas regarding Continental drift theory.

The earliest fossils attributed to green algae date from the Precambrian (ca. 1200 mya).^{[46][47]} The resistant outer walls of prasinophyte cysts (known as phycmata) are well preserved in fossil deposits of the Paleozoic (ca. 250-540 mya). A filamentous fossil (Proterocladus) from middle Neoproterozoic deposits (ca. 750 mya) has been attributed to the Cladophorales, while the oldest reliable records of the Bryopsidales, Dasycladales) and stoneworts are from the Paleozoic.^{[42][48]}

Structure, growth and development

Most of the solid material in a plant is taken from the atmosphere. Through a process known as photosynthesis, most plants use the energy in sunlight to convert carbon dioxide from the atmosphere, plus water, into simple sugars. (Parasitic plants, on the other hand, use the resources of its host to grow.) These sugars are then used as building blocks and form the main structural



A petrified log in Petrified Forest National Park, Arizona

component of the plant. Chlorophyll, a green-colored, magnesium-containing pigment is essential to this process; it is generally present in plant leaves, and often in other plant parts as well.

Plants usually rely on soil primarily for support and water (in quantitative terms), but also obtain compounds of nitrogen, phosphorus, potassium, magnesium and other elemental nutrients. Epiphytic and lithophytic plants depend on air and nearby debris for nutrients, and carnivorous plants supplement their nutrient requirements with insect prey that they capture. For the majority of plants to grow successfully they also require oxygen in the atmosphere and around their roots (soil gas) for respiration. Plants use oxygen and glucose (which may be produced from stored starch) to provide energy.^[49] Some plants grow as submerged aquatics, using oxygen dissolved in the surrounding water, and a few specialized vascular plants, such as mangroves, can grow with their roots in anoxic conditions.



The leaf is usually the primary site of photosynthesis in plants.^[50]

Factors affecting growth

The genotype of a plant affects its growth. For example, selected varieties of wheat grow rapidly, maturing within 110 days, whereas others, in the same environmental conditions, grow more slowly and mature within 155 days.^[50]

Growth is also determined by environmental factors, such as temperature, available water, available light, carbon dioxide and available nutrients in the soil. Any change in the availability of these external conditions will be reflected in the plant's growth.

Biotic factors are also capable of affecting plant growth. Plants compete with other plants for space, water, light and nutrients. Plants can be so crowded that no single individual produces normal growth, causing etiolation and chlorosis. Optimal plant growth can be hampered by grazing animals, suboptimal soil composition, lack of mycorrhizal fungi, and attacks by insects or plant diseases, including those caused by bacteria, fungi, viruses, and nematodes.^[50]



There is no photosynthesis in deciduous leaves in autumn.

Simple plants like algae may have short life spans as individuals, but their populations are commonly seasonal. Other plants may be organized according to their seasonal growth pattern: annual plants live and reproduce within one growing season, biennial plants live for two growing seasons and usually reproduce in second year, and perennial plants live for many growing seasons and continue to reproduce once they are mature. These designations often depend on climate and other environmental factors; plants that are annual in alpine or temperate regions can be biennial or perennial in warmer climates. Among the vascular plants, perennials include both evergreens that keep their leaves the entire year, and deciduous plants that lose their leaves for some part of it. In temperate and boreal climates, they generally lose their leaves during the winter; many tropical plants lose their leaves during the dry season.

The growth rate of plants is extremely variable. Some mosses grow less than 0.001 millimeters per hour (mm/h), while most trees grow 0.025-0.250 mm/h. Some climbing species, such as kudzu, which do not need to produce thick supportive tissue, may grow up to 12.5 mm/h.

Plants protect themselves from frost and dehydration stress with antifreeze proteins, heat-shock proteins and sugars (sucrose is common). LEA (Late Embryogenesis Abundant) protein expression is induced by stresses and protects other proteins from aggregation as a result of desiccation and freezing.^[51]

Effects of freezing

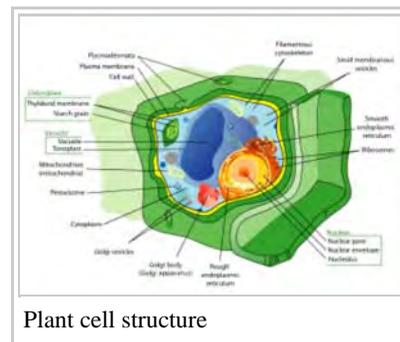
When water freezes in plants, the consequences for the plant depend very much on whether the freezing occurs within cells (intracellularly) or outside cells in intercellular spaces (Glerum 1985).^[52] Intracellular freezing, which usually kills the cell (Lyons et al. 1979)^[53] regardless of the hardiness of the plant and its tissues, seldom occurs in nature because rates of cooling are rarely high enough to support it. Rates of cooling of several degrees Celsius per minute are typically needed to cause intracellular formation of ice (Mazur 1977).^[54]

At rates of cooling of a few degrees Celsius per hour, segregation of ice occurs in intercellular spaces, the “extraorgan ice” of Sakai and Larcher (1987)^[55] and their coworkers. This may or may not be lethal, depending on the hardness of the tissue.

The process of intercellular ice formation was described by Glerum (1985).^[52] At freezing temperatures, water in the intercellular spaces of plant tissue freezes first, though the water may remain unfrozen until temperatures drop below $-7\text{ }^{\circ}\text{C}$ ($19\text{ }^{\circ}\text{F}$). After the initial formation of ice intercellularly, the cells shrink as water is lost to the segregated ice, and the cells undergo freeze-drying. This dehydration is now considered the fundamental cause of freezing injury.

Plant cell

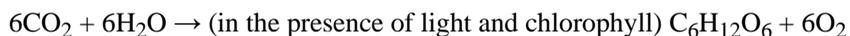
Plant cells are typically distinguished by their large water-filled central vacuole, chloroplasts, and rigid cell walls that are made up of cellulose, hemicellulose, and pectin. Cell division is also characterized by the development of a phragmoplast for the construction of a cell plate in the late stages of cytokinesis. Just as in animals, plant cells differentiate and develop into multiple cell types. Totipotent meristematic cells can differentiate into vascular, storage, protective (e.g. epidermal layer), or reproductive tissues, with more primitive plants lacking some tissue types.^[56]



Physiology

Photosynthesis

Plants are photosynthetic, which means that they manufacture their own food molecules using energy obtained from light. The primary mechanism plants have for capturing light energy is the pigment chlorophyll. All green plants contain two forms of chlorophyll, chlorophyll *a* and chlorophyll *b*. The latter of these pigments is not found in red or brown algae. The simple equation of photosynthesis is as follows:-



Immune system

By means of cells that behave like nerves, plants receive and distribute within their systems information about incident light intensity and quality. Incident light that stimulates a chemical reaction in one leaf, will cause a chain reaction of signals to the entire plant via a type of cell termed a *bundle sheath cell*. Researchers, from the Warsaw University of Life Sciences in Poland, found that plants have a specific memory for varying light conditions, which prepares their immune systems against seasonal pathogens.^[57] Plants use pattern-recognition receptors to recognize conserved microbial signatures. This recognition triggers an immune response. The first plant receptors of conserved microbial signatures were identified in rice (XA21, 1995)^[58] and in *Arabidopsis thaliana* (FLS2, 2000).^[59] Plants also carry immune receptors that recognize highly variable pathogen effectors. These include the NBS-LRR class of proteins.

Internal distribution

Vascular plants differ from other plants in that nutrients are transported between their different parts through specialized structures, called xylem and phloem. They also have roots for taking up water and minerals. The xylem moves water and minerals from the root to the rest of the plant, and the phloem provides the roots with sugars and other nutrient produced by the leaves.^[56]

Ecology

The photosynthesis conducted by land plants and algae is the ultimate source of energy and organic material in nearly all ecosystems. Photosynthesis radically changed the composition of the early Earth's atmosphere, which as a result is now 21% oxygen. Animals and most other organisms are aerobic, relying on oxygen; those that do not are confined to relatively rare anaerobic environments. Plants are the primary producers in most terrestrial ecosystems and form the basis of the food web in those ecosystems. Many animals rely on plants for shelter as well as oxygen and food.

Land plants are key components of the water cycle and several other biogeochemical cycles. Some plants have coevolved with nitrogen fixing bacteria, making plants an important part of the nitrogen cycle. Plant roots play an essential role in soil development and prevention of soil erosion.

Distribution

Plants are distributed worldwide in varying numbers. While they inhabit a multitude of biomes and ecoregions, few can be found beyond the tundras at the northernmost regions of continental shelves. At the southern extremes, plants have adapted tenaciously to the prevailing conditions. (See Antarctic flora.)

Plants are often the dominant physical and structural component of habitats where they occur. Many of the Earth's biomes are named for the type of vegetation because plants are the dominant organisms in those biomes, such as grasslands and forests.

Ecological relationships

Numerous animals have coevolved with plants. Many animals pollinate flowers in exchange for food in the form of pollen or nectar. Many animals disperse seeds, often by eating fruit and passing the seeds in their feces. Myrmecophytes are plants that have coevolved with ants. The plant provides a home, and sometimes food, for the ants. In exchange, the ants defend the plant from herbivores and sometimes competing plants. Ant wastes provide organic fertilizer.

The majority of plant species have various kinds of fungi associated with their root systems in a kind of mutualistic symbiosis known as mycorrhiza. The fungi help the plants gain water and mineral nutrients from the soil, while the plant gives the fungi carbohydrates manufactured in photosynthesis. Some plants serve as homes for endophytic fungi that protect the plant from herbivores by producing toxins. The fungal endophyte, *Neotyphodium coenophialum*, in tall fescue (*Festuca arundinacea*) does tremendous economic damage to the cattle industry in the U.S.

Various forms of parasitism are also fairly common among plants, from the semi-parasitic mistletoe that merely takes some nutrients from its host, but still has photosynthetic leaves, to the fully parasitic broomrape and toothwort that acquire all their nutrients through connections to the roots of other plants, and so have no chlorophyll. Some plants, known as myco-heterotrophs, parasitize mycorrhizal fungi, and hence act as epiparasites on other plants.

Many plants are epiphytes, meaning they grow on other plants, usually trees, without parasitizing them. Epiphytes may indirectly harm their host plant by intercepting mineral nutrients and light that the host would otherwise receive. The weight of large numbers of epiphytes may break tree limbs. Hemiepiphytes like the strangler fig begin as epiphytes but eventually set their own roots and overpower and kill their host. Many orchids, bromeliads, ferns and mosses often grow as epiphytes. Bromeliad epiphytes accumulate water in leaf axils to form phytotelmata that may contain complex aquatic food webs.^[60]

Approximately 630 plants are carnivorous, such as the Venus Flytrap (*Dionaea muscipula*) and sundew (*Drosera* species). They trap small animals and digest them to obtain mineral nutrients, especially nitrogen and phosphorus.^[61]

Importance

The study of plant uses by people is termed economic botany or ethnobotany; some consider economic botany to focus on modern cultivated plants, while ethnobotany focuses on indigenous plants cultivated and used by native peoples. Human cultivation of plants is part of agriculture, which is the basis of human civilization. Plant agriculture is subdivided into agronomy, horticulture and forestry.

Foods and beverages

Much of human nutrition depends on plants, either directly through foods and beverages consumed by people, or indirectly as feed for animals or the flavoring of foods. The science of agriculture deals with the planting, raising, nutrition, and harvest of food crops, and has played a key role in the history of world civilizations.



The Venus flytrap, a species of carnivorous plant.

Human nutrition depends to a large extent on cereals, especially maize (or corn), wheat, rice, oats, and millet. Large areas of many countries are given over to the cultivation of cereals for local consumption or export to other countries. Livestock animals including cows, pigs, sheep, goats and camels are all herbivores; and most feed primarily or entirely on cereal plants. Cereals are staple crops, meaning that they provide calories (in the form of complex carbohydrates such as starch) that are needed to fuel daily activities, and thus form the foundation of a daily diet. Other staple crops include potatoes, cassava, yams, and legumes.



Mechanical harvest of oats.

Human food also includes vegetables, which consist principally of leaves and stems eaten as food. Vegetables are important for the vitamins, minerals, and dietary fiber they supply. Fruits provide a higher quantity of sugars and have a sweeter taste than vegetables. However, whether a particular food is considered a "vegetable" or a "fruit" will depend on context, since the word *fruit* has a more precise definition in botany than it does in general use. Nuts and seeds, including foods such as peanuts, walnuts, almonds, and pistachios, contain unsaturated fats that are also necessary for a healthy diet. As with fruits, the terms *nut* and *seed* have stricter definitions in plant science.

Many plants are used to flavor foods. Such plants include herbs (e.g. rosemary and mint), which come from the green leafy parts of plants, and spices (e.g. cumin and cinnamon), which come from other plant parts. Some plants produce edible flowers, which may be added to salads or used to decorate foods. Sweeteners such as sugar and stevia are derived from plants. Sugar is obtained mainly from sugar cane and sugar beet, and honey is created when bees regurgitate the nectar from flowers. Cooking oils and margarine come from maize, soybean, rapeseed, safflower, sunflower, olive and others. Food additives include gum arabic, guar gum, locust bean gum, starch and pectin.

Plants are also the source of beverages produced either by infusion, such as coffee and tea; by fermentation, such as beer and wine; or by distillation, such as whisky, vodka, rum, and other alcoholic spirits.

Nonfood products

Plants are the source of many natural products such as essential oils, natural dyes, pigments, waxes, resins, tannins, alkaloids, amber and cork. Products derived from plants include soaps, shampoos, perfumes, cosmetics, paint, varnish, turpentine, rubber, latex, lubricants, linoleum, plastics, inks, and gums. Renewable fuels from plants include firewood, peat and many other biofuels. Coal and petroleum are fossil fuels derived from the remains of plants. Olive oil has been used in lamps for centuries to provide illumination.



Timber in storage for later processing at a sawmill.

Structural resources and fibers from plants are used in both the construction of dwellings and the manufacture of clothing. Wood is used not only for buildings, boats, and furniture, but also for smaller items such as musical instruments and sports equipment. Wood also may be pulped for the manufacture of paper and cardboard. Cloth is often made from cotton, flax, ramie or synthetic fibers derived from cellulose, such as rayon and acetate. The thread that is used to sew cloth likewise comes from plant fibers. Hemp and jute are grown for their fibers, which may be woven into rope or rough sacking.

Plants are also a primary source of basic chemicals, both for their medicinal and physiological effects, as well as for the industrial synthesis of a vast array of organic chemicals. Medicines derived from plants include aspirin, taxol, morphine, quinine, reserpine, colchicine, digitalis and vincristine. There are hundreds of herbal supplements such as ginkgo, Echinacea, feverfew, and Saint John's wort. Pesticides derived from plants include nicotine, rotenone, strychnine and pyrethrins. Certain plants contain psychotropic chemicals that are extracted and ingested, including tobacco, cannabis (marijuana), opium, and cocaine. Poisons from plants include ricin, hemlock and curare.

Aesthetic uses

Thousands of plant species are cultivated for aesthetic purposes as well as to provide shade, modify temperatures, reduce wind, abate noise, provide privacy, and prevent soil erosion. Plants are the basis of a multibillion-dollar per year tourism industry, which includes travel to historic gardens, national parks, rainforests, forests with colorful autumn leaves, and the National Cherry Blossom Festival.

While some gardens are planted with food crops, many are planted for aesthetic, ornamental, or conservation purposes. Arboreta and botanical gardens are public collections of living plants. In private outdoor gardens, lawn grasses, shade trees, ornamental trees, shrubs, vines, herbaceous perennials and bedding plants are used. Gardens may cultivate the plants in a naturalistic state, or may sculpture their growth, as with topiary or espalier. Gardening is the most popular leisure activity in the U.S., and working with plants or horticulture therapy is beneficial for rehabilitating people with disabilities.

Plants may also be grown or kept indoors as houseplants, or in specialized buildings such as greenhouses that are designed for the care and cultivation of living plants. Venus Flytrap, sensitive plant and resurrection plant are examples of plants sold as novelties. There are also art forms specializing in the arrangement of cut or living plant, such as bonsai, ikebana, and the arrangement of cut or dried flowers. Ornamental plants have sometimes changed the course of history, as in tulipomania.

Architectural designs resembling plants appear in the capitals of ancient Egyptian columns, which were carved to resemble either the Egyptian white lotus or the papyrus. Images of plants are often used in painting and photography, as well as on textiles, money, stamps, flags and coats of arms.

Scientific and cultural uses

Basic biological research has often been done with plants. In genetics, the breeding of pea plants allowed Gregor Mendel to derive the basic laws governing inheritance, and examination of chromosomes in maize allowed Barbara McClintock to demonstrate their connection to inherited traits. The plant *Arabidopsis thaliana* is used in laboratories as a model organism to understand how genes control the growth and development of plant structures. Space stations or space colonies may one day rely on plants for life support.

Ancient trees are revered and many are famous. Tree rings themselves are an important method of dating in archeology, and serve as a record of past climates.

Plants figure prominently in mythology, religion and literature. They are used as national and state emblems, including state trees and state flowers. Plants are often used as memorials, gifts and to mark special occasions such as births, deaths, weddings and holidays. The arrangement of flowers may be used to send hidden messages.

The field of ethnobotany studies plant use by indigenous cultures, which helps to conserve endangered species as well as discover new medicinal plants.

Negative effects

Weeds are uncultivated and usually unwanted plants growing in managed environments such as farms, urban areas, gardens, lawns, and parks. People have spread plants beyond their native ranges and some of these introduced plants become invasive, damaging existing ecosystems by displacing native species. Invasive plants cause costly damage in crop losses annually by displacing crop plants, they further increase the cost of production and the use of chemicals to control them, which in turn affects the environment.

Plants may cause harm to animals, including people. Plants that produce windblown pollen invoke allergic reactions in people who suffer from hay fever. A wide variety of plants are poisonous. Toxalbumins are plant poisons fatal to most mammals and act as a serious deterrent to consumption. Several plants cause skin irritations when touched, such as poison ivy. Certain plants contain psychotropic chemicals, which are extracted and ingested or smoked, including tobacco, cannabis (marijuana), cocaine and opium. Smoking causes damage to health or even death, while some drugs may also be harmful or fatal to people.^{[62][63]} Both illegal and legal drugs derived from plants may have negative effects on the economy, affecting worker productivity and law enforcement costs.^{[64][65]} Some plants cause allergic reactions when ingested, while other plants cause food intolerances that negatively affect health.



A rose espalier at Niedernhall in Germany.



Capitals of ancient Egyptian columns decorated to resemble papyrus plants. (at Luxor, Egypt)



Barbara McClintock (1902–1992) was a pioneering cytogeneticist who used maize (or corn) to study the mechanism of inheritance of traits.

See also

- Biosphere
- DPVweb
- Evolutionary history of plants
- Leaf sensor
- Plant cognition
- Plant defense against herbivory
- Plant identification
- The Plant List
- Plants in space

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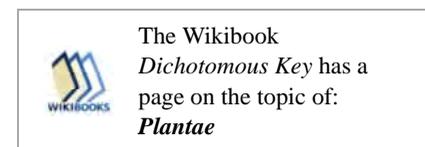
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- Interactive Cronquist classification (<http://florabase.calm.wa.gov.au/phylogeny/cronq88.html>)
- Plant Resources of Tropical Africa (<http://www.prota.org/uk/About+Prota/>)
- Tree of Life (http://tolweb.org/Green_plants)



Botanical and vegetation databases

- African Plants Initiative database (http://www.aluka.org/action/doBrowse?sa=1&sa_sel=)
- Australia (<http://www.anbg.gov.au/cpbr/databases/>)
- Chilean plants at *Chilebosque* (<http://www.chilebosque.cl/>)
- e-Floras (Flora of China, Flora of North America and others) (<http://www.efloras.org/index.aspx>)
- Flora Europaea (<http://rbg-web2.rbge.org.uk/FE/fe.html>)
- Flora of Central Europe (<http://www.floraweb.de/>) (**German**)
- Flora of North America (http://www.efloras.org/flora_page.aspx?flora_id=1)

- List of Japanese Wild Plants Online (http://www.alpine-plants-jp.com/botanical_name/list_of_japanese_wild_plants_abelia_buxus.htm)
- Meet the Plants-National Tropical Botanical Garden (http://www.ntbg.org/plants/choose_a_plant.php)
- Lady Bird Johnson Wildflower Center – Native Plant Information Network at University of Texas, Austin (<http://www.wildflower.org/>)
- The Plant List (<http://www.theplantlist.org/>)
- United States Department of Agriculture (<http://plants.usda.gov/>) not limited to continental US species

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Categories: Plants | Plant taxonomy | Kingdoms (biology)

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